3. POTENTIAL FUTURES

prepared by

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Climate

The regional climate through the end of the 21st century will likely be warmer and wetter. The questions of how much warmer and how much wetter may be answered by examining output from two General Circulation Models (GCMs): the Canadian Model (CGCM1) [1-4] and the United Kingdom Hadley Model - (HadCM2) [1-5]. These models differ from ones in the recent past not only in their sophistication with which they handle cloud development and ocean currents for example, but also because they are transient and they include the effects of aerosols. These aerosols mask the warming effects of increasing carbon dioxide, an effect which will only likely be temporary. The steady-state nature of previous models only allowed an evaluation of effects from an "instantaneous doubling of CO_2," rather than from a more realistic steady increase. The two models recreate the current conditions [3-1] well but suggest slightly different climate scenarios for the Great Lakes region.

Figures 3.1 and 3.2 show that in general, the CGCM1 scenario is warmer and drier than the HadCM2 scenario. The models differ only slightly for the period 2025-2034 in summer. The models suggest that minimum summer temperatures will increase by 1.8-3.6°F (1-2°C) across the region, while maximum temperatures will increase 0-1.8°F (0-1°C). More

warming will occur in the western part of the region than in the eastern part. The net change may be a decrease in the diurnal temperature range in the west and an increase in the east. The decreased diurnal temperature range may suggest slightly more cloudiness or humidity over the western part of the region. The models also suggest that summer precipitation will increase by 15-25%.

Larger differences between the two models exist in winter. Increases in the minimum temperature of 7.2 - 10.8°F (4-6°C) from southeast to northwest are projected by the CGCM1 scenario and 0.9-4.5°F (0.5-2.5°C) from east to west by the HadCM2 scenario. Increases in the maximum temperature of 3.6 -5.4°F (2-3°C) from north to south are projected by the CGCM1 scenario. and increases 0.9-4.5°F (0.5-2.5°C) from west to east by the Hadley scenario. Wintertime precipitation is slightly less in the HadCM2 than in the CGCM1 scenario, which generates precipitation that is similar to present day values.

Both models suggest more significant changes in mean temperature and precipitation for the period 2090-2099, than for the period 2025-2034. They also differ from each other more. For example in summer, the CGCM1 scenario shows average temperature increases of 7.2°F (4°C), while the HadCM2 scenario shows increases around 3.6°F (2°C). Precipitation varies considerably across the region and between the two models also. The CGCM1 scenario shows near-drought conditions across the northwestern portion of the region and increases of 20-40% everywhere else. The HadCM2 scenario shows general precipitation increases of 25% with near flood conditions (increase of 70%) over northern lower Michigan.

In winter, the CGCM1 scenario shows average temperature increases of 10.8-12.6°F (6-7°C). More warming occurs for the minimum temperatures and more warming occurs to the south
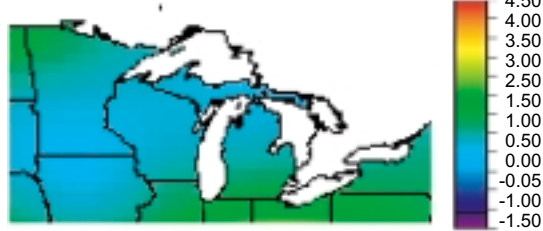
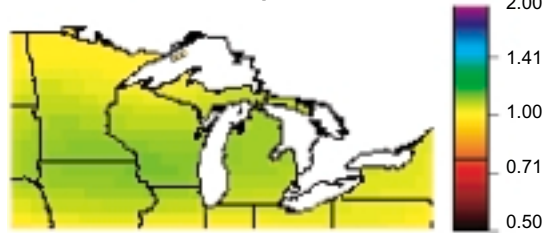**CGCM1 2030 Minuimum Temperature JJA**

HadCM2 2030 Minuimum Temperature JJA
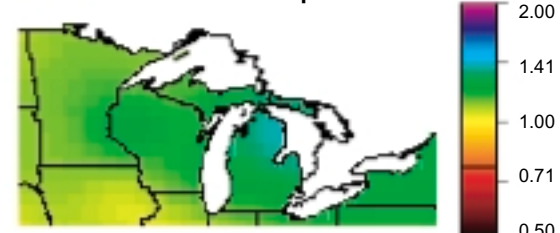
CGCM1 2030 Maximum Temperature JJA
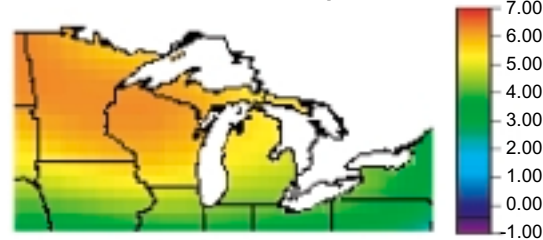
HadCM2 2030 Maximum Temperature JJA

CGCM1 2030 Precipitation JJA

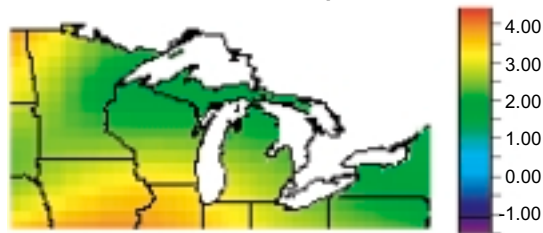**HadCM2 2030 Precipitation JJA**
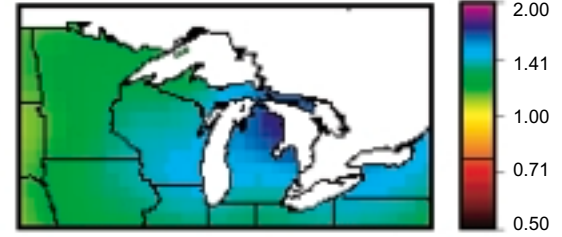
CGCM1 2030 Minimum Temperature DJF
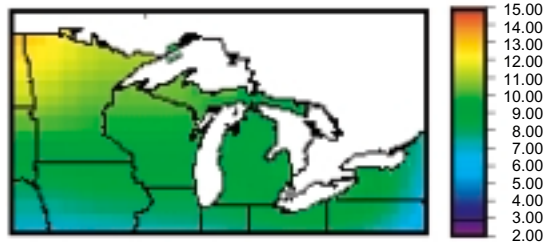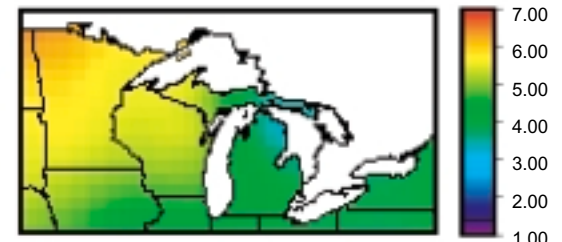
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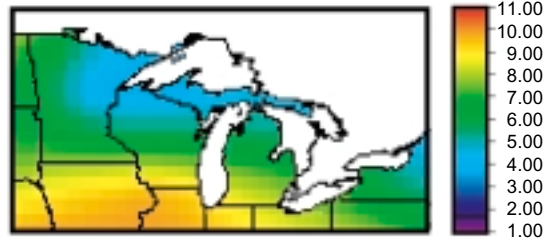
HadCM2 2030 Maximum Temperature DJF
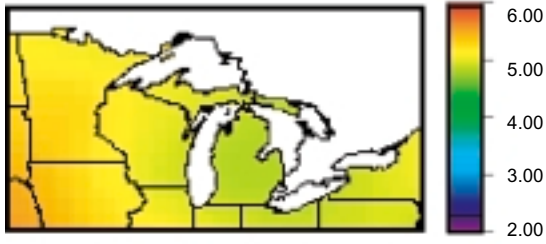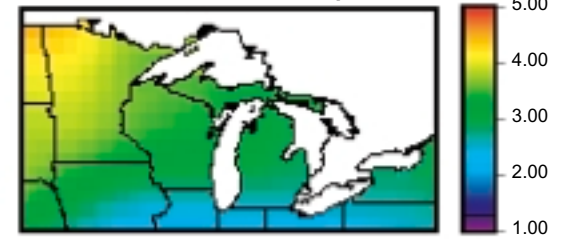
CGCM1 2030 Precipitation DJF
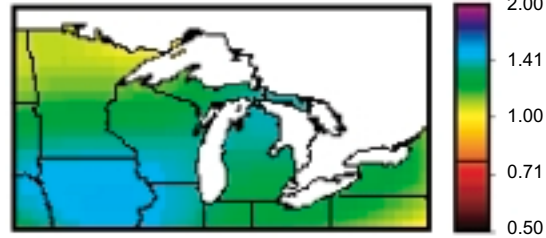
HadCM2 2030 Precipitation DJF

Figure 3.1: Future climate projections from the Hadley (HadCM2) and the Canadian (CGCM1) general circulation models for winter (DFJ) and summer (JJA) for the period 2030. Plotted values are for VEMAP averages at 0.5° resolution. Output includes maximum (MAX) and minimum (MIN) surface temperature changes (°C) and precipitation changes (%) from baseline (1961-1990) model scenarios [3.2].
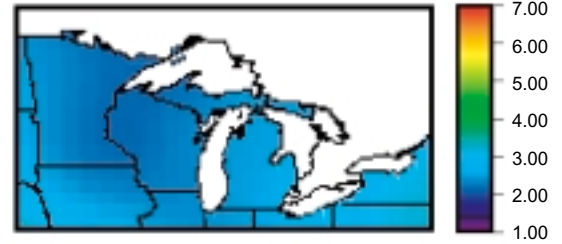
Figure 3.2: Future climate projections from the Hadley (HadCM2) and the Canadian (CGCM1) general circulation models for winter (DFJ) and summer (JJA) for the period 2095. Plotted values are for VEMAP averages at 0.5º resolution. Output includes maximum (MAX) and minimum (MIN) surface temperature changes (ºC) and precipitation changes (%) from baseline (1961-1990) model scenarios [3.2].
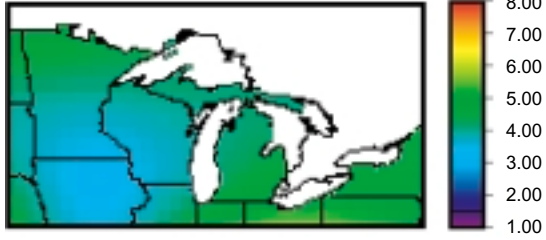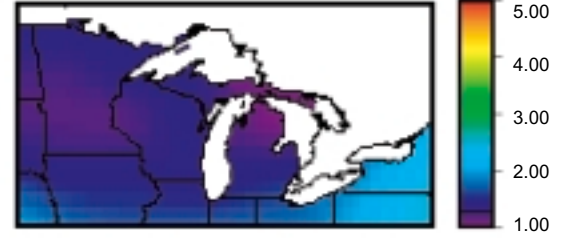
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than to the north – suggesting an enhanced horizontal temperature gradient and possibly an enhanced storm track. The HadCM2 scenario shows average temperature increases of 7.2°F (4°C) with a weakening of the horizontal temperature gradient. Both models show about a 20% increase in precipitation across much of the region. The CGCM1 scenario shows a 40% increase over Iowa – just to the southwest of the Great Lakes region.

Understanding the mean temperature and precipitation changes from the models is important, but understanding the corresponding day-to-day weather (and weather extremes) associated with those changes is tantamount to being able to understand and to deal with climate change. Unfortunately, such changes are difficult enough to assess in winter and even more difficult in summer. However, some assessments of local weather changes can be made based on the model projections of large scale conditions and simple statistics. For example, the probability that Chicago will experience 10 or more days in the summer with high temperatures exceeding 90°F (32°C) is projected to go from a 1-in-25 year event now to a 1-in-10 year event by the end of next century. The probability that Chicago will experience 6 or more days in the winter with low temperatures below 0°F (-18°C) is projected to go from a 1-in-10 year event now to a 1-in-50 year event by the end of the 21st century. By the end of the 21st century, the typical winter may be comparable to what we experience now during a moderate to strong El Niño. The coldest winters may be comparable to the normal winters we experience now. Snowfall totals may be half the current normal totals with lake-effect snow being significantly reduced (Focus: *Climate Change and Lake Effect Snow*), but lake-effect rain being increased. Both the CGCM1 and the HadCM2 scenarios suggest more zonal flow patterns. In winter this translates to more Pacific systems, more Gulf of Mexico systems, and fewer Alberta Clippers. Alberta Clippers are a primary source for reinforcing cold air over the Great Lakes in winter. Fewer outbreaks likely means less lake-effect snow.

Population & Economy

In some sense it is considerably more difficult to imagine what the future socioeconomic situation for the Great Lakes region

GENERAL CIRCULATION MODEL (GCM) QUICK COMPARISON		
Model	HadCM2	CGCM1
Type	Transient	Transient
Aerosols	Included	Included
Precipitation	much wetter	wetter
Temperature	warmer	much warmer
Great Lakes	Included	Not included

will be than to consider how the climate itself will change. For example, the auto industry is one of the leading industries in the region, and while its existence is certainly not in jeopardy, its future and exactly how it conducts business will almost certainly be more impacted by the (political) response to climate change than by the climate change itself. The auto industry and climate change are closely coupled – what happens to one affects the other, which makes using separable climate and socioeconomic scenarios somewhat constraining. Other industries are not so much coupled (in a two-way interaction sense) as they are driven (in a one-way forced sense), like the electric industry, for example. What happens politically as a result of climate change will have an impact on this industry (it is responsible for about a third of atmospheric CO_2), but climate change itself, with its periods of extreme weather, will also have an impact. A third type of industry, where climate change will have primarily direct impacts is something like recreation. Water levels and frequency of extreme weather are likely to directly impact how many people go to the beaches or go boating for example.

The US National Assessment contracted NPA Data Services to produce regional socioeconomic projections. The socioeconomic scenarios include basic information about population and wealth and the results are shown in Figure 3.3 [1-7]. Three alternate growth projections, baseline, high, and low were developed, extending over the next few decades. The baseline scenario assumes that the current trends will continue. The high and low growth scenarios were intended to be near the limits of plausibility. All three projections assume a relatively peaceful

world. Population is calculated from births, immigrantion, and deaths.

National projections for the baseline scenario were based on assumptions about population and follow the latest Census Bureau projections about fertility and mortality. The number of immigrants is allowed to increase at a rate of 1.4 % per year until 2025 after which it remains a constant proportion of the population. The result is a baseline projection with a national population growth rate of 0.87% between 1997 and 2025 and a rate of 0.65% from 2025 to 2050. Additionally a national high growth scenario assumed an open door US immigration policy. The result was a growth rate of 1.18% from 1997-2025 and a growth rate of 1.28% from 2025-2050. Finally a national low growth scenario was generated based on slowing and eventually stabilizing population and very limited immigration. The corresponding low growth rates are 0.41% and 0.20%.

The size of the economy is determined by two variables, employment and productivity in the NPA models. Employment is determined by population and labor force participation rates. Productivity comes from the gross domestic product (GDP) per person. In the national baseline scenario the growth in GDP per person averages 1.26% from 1997-2025 and then to 1.12% by 2050. In the high growth scenario dramatic growth was assumed with productivity allowed to grow by 2.4 % per year from 1997-2050. In the low growth scenario, productivity was slower and eventually virtually stagnant. The rates were 1.23% until 2025 and 0.13% to 2050.

These national projections were converted to regional projections using the Regional Economic Information System (REIS) of the Bureau of Economic Analysis of the US Department of Commerce. The regional projections cover IL, IN, MI, OH, WI, and MN, which is not exactly the Great Lakes region, but is likely sufficiently close to get a sense of a possible trend. The major differences with respect to employment involve the self employed and those employed in the military. These are handled more thoroughly in the REIS database. With respect to the economy, personal income data are used in the REIS database and are available at the county level while GDP is only available at the national level. For the future, employment projections show an increase for most industries from

Population: 1967-2050

Employment: 1967-2050
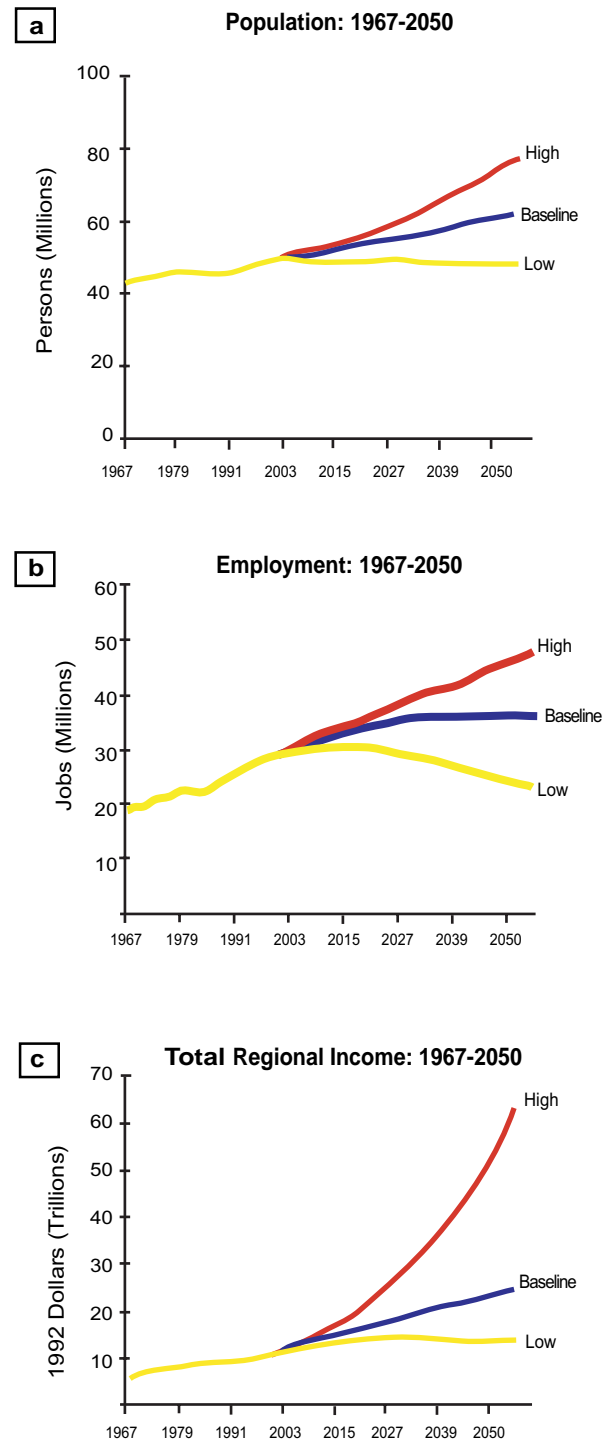
Total Regional Income: 1967-2050

Figure 3.3: Socioeconomic trends for: a) population, b) employment, and c) total regional income for Illinois, Indiana, Michigan, Ohio, Wisconsin, and Minnesota.

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an absolute-dollar perspective (Figure 3.4) but decreases in automobile manufacturing and farming and a slight gain in lumber and wood manufacturing from a percentage-contribution perspective (Figure 3.5). Employment in amusement and recreation are expected to increase by approximately 35% between 2000 and 2050.

Year	1967	1990	2020	2050
Farm	13	7	5	11
Forestry and Fisheries	1	3	9	15
Mining	3	3	4	6
Construction	29	39	86	129
Manufacturing	173	185	231	305
Transp., Comm. & Public Utilities	31	43	70	95
Wholesale Trade	27	46	88	127
Retail Trade	50	61	104	146
Finance, Insurance & Real Estate	21	41	102	157
Services	60	157	359	534
Government Activities	52	91	136	191
Totals	425	607	1051	1491
Population	43,006	46,463	53,570	62,097
Income	565,892	940,607	1,698,387	2,483,407
Per Capita Income	13,159	20,244	31,704	39,992

Figure 3.4: Regional (i.e., Illinois, Indiana, Michigan, Ohio, Wisconsin, and Minnesota) economy: Current and future projections for selected industries and four different time periods. (1992 billions of dollars; population in millions) [3-3].
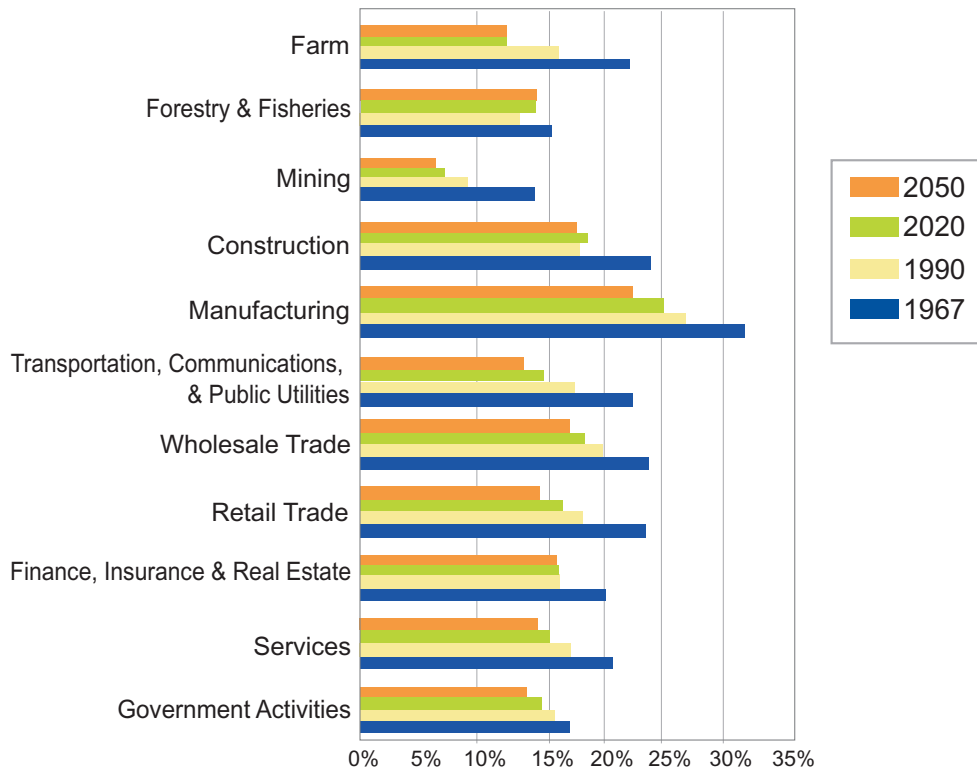

Figure 3.5: Region 3 (i.e., IIllinois, Indiana, Michigan, Ohio, and Wisconsin,) contributions (%) to the national total for selected industries and four different time periods [3-3].

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FOCUS

CLIMATE CHANGE AND LAKE-EFFECT SNOW

study conducted by

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Lake-effect snow is a common cold season phenomenon in the Great Lakes region, occurring most frequently in late autumn and early winter. This type of snow results from the rapid warming and moistening of Arctic air masses that pass over lakes that are still relatively warm. The Arctic air becomes unstable and the resulting convection forms clouds and precipitation. The precipitation falls over and downwind of the lakes. For very cold air masses, temperatures remain below freezing even after passage over the warmer lakes, causing the precipitation to fall as snow. Lake-effect snow causes considerable enhancement of snowfall in narrow snowbelts along the downwind lakeshores. For example, Detroit, Michigan, on the western (upwind) shore of Lake Erie receives an average of 42 in yr^{-1}, while Buffalo, New York, on the eastern (downwind) shore of Lake Erie, receives an average of 92 in yr^{-1}. Toronto, Ontario, on the northwestern (upwind) shore of Lake Ontario, receives about 54 in yr^{-1}, while Syracuse, New York, located to the southeast (downwind) shore of Lake Ontario, receives 109 in yr^{-1} and is the snowiest metropolitan area in the United States. The lake-effect snow season typically extends from November through February over all of the Great Lakes except for Lake Erie, which normally freezes over by the end of January, putting an abrupt end to the lake-effect snowfall in places like Erie, PA and Buffalo, NY for the remainder of the winter.

Lake-effect snow creates transportation problems and results in additional costs to keep roads clear. A major transportation artery, Interstate 90, passes along the southern shore of Lake Erie and is vulnerable to lake-effect snow storms. Increased property damage, injuries, and deaths due to accidents and exertion accompany such events. Major airports at Cleveland and Buffalo are also vulnerable to disruptions. The roofs of buildings in the snowbelts must be built to support heavier loads of snow than for locations away from the snowbelts [F3-1]. Retail sales may drop temporarily. A single severe lake-effect snowstorm near Cleveland, OH in November 1996 resulted in 8 deaths, hundreds of human injuries, widespread power outages, damage to numerous buildings, and over $30 million in economic losses ([F3-2]; S.A.Changnon, personal communication). On the positive side, there is a large private snow removal business sector that benefits from the snowfall. Sales of winter-related products may increase. Lake-effect snowfall also supports an important winter recreational industry in some parts of the Great Lakes. Although there is not a large downhill ski industry in the Lake Erie snowbelt, many of the Midwest's premier downhill ski resorts are located in the snowbelts of the other lakes in the region.

Abnormally light snowfall amounts during the winter season have also created significant negative impacts, particularly when snowfall deficiencies have been widespread and the associated losses have affected many locations throughout the Great Lakes region. Such was the case over most of the Great Lakes region during the 1997-1998 El Niño year. The widespread nature of this event resulted in impacts over a large area. For example, business at Midwestern ski resorts was down 50% and losses were estimated at $120 million (S.A.Changnon, personal communication).

Recent studies show that past changes in lake-effect snowfall on decadal time frames were related to climatic shifts. For example, lake-effect snowfall on the lee shore of Lake Michigan increased from the 1930s into the 1970s – coincident with a decrease in mean winter temperature [F3-3]. More recently, changes in heavy lake-effect snow events were evaluated as part of the current assessment for the Lake Erie snowbelt. Lighter events certainly occur more frequently and contribute significantly to the total annual snowfall totals, but Great Lakes residents have adapted to them so they are not nearly the societal concern that heavy events are. For the period 1950-1995, all occurrences of lake-effect snowfall in excess of 8 inches at Erie, PA and Westfield, NY were identified. Four surface conditions (air temperature, lake-air temperature difference, wind speed, wind direction) were found to be highly correlated with the occurrence of heavy lake-effect snow, when they occur within certain favorable ranges simultaneously. In the 1950-1995 observational data, favorable conditions occurred approximately 17 times per decade. In the HadCM2 simulation for the 1960-1989 period, favorable conditions occurred approximately 15 times per decade, very similar to the observational record.

The simultaneous occurrence of these favorable conditions decreases from 15 to 7 times per decade in the HadCM2 model between the 1960-1989 and 2070-2099 period. This decrease occurred – even though the lake-effect season was extended through the end of February to account for the fact that Lake Erie would no longer likely freeze over – almost entirely because of a drop in the number of days below freezing. When the simultaneous occurrence of the other favorable conditions was examined, there was very little difference between the 1960-1989 and the 2070-2099 periods. Even the frequency of occurrence of lake-air temperature differences did not change because the lake tem-

perature increased about the same amount as the air temperature. This suggests that the decrease in heavy lake-effect snow may be accompanied by an increase in winter-time lake-effect rain events, which are now most frequent in the autumn [F3-4]. A similar analysis for the Lake Michigan and Lake Superior snowbelts indicates that the southern Lake Michigan snowbelt will experience a decrease in the number of below-freezing days in the late 21st Century similar to the Lake Erie snowbelt, but little change in the other variables. However, for the Lake Superior snowbelt, the mean winter temperature remains below 32°F and there is little change both in the number of below-freezing days and the frequency of favorable ranges of the other variables. Thus, there may be little change in the frequency of heavy lake-effect snow in the Lake Superior snowbelt and a substantial decrease in the southern Lake Michigan and Lake Erie snowbelts. The fact that air-temperature was found to be the primary determining factor in reducing the frequency of heavy lake-effect events in this study suggests that the frequency of light(er) events may be influenced in the same way. Figure F3.1 summarizes the anticipated regional impacts of climate change on lake-effect snow patterns – suggesting almost no change in the northernmost belts but approximately a 50% decrease in southernmost belts. The spatial variability demonstrates that the impacts of climate change as portrayed by the HadCM2 model can be greatly influenced by subtle regional differences. The overall warmer scenario portrayed by the CGCM1 model suggests an even greater reduction in lake-effect snow than was found here.
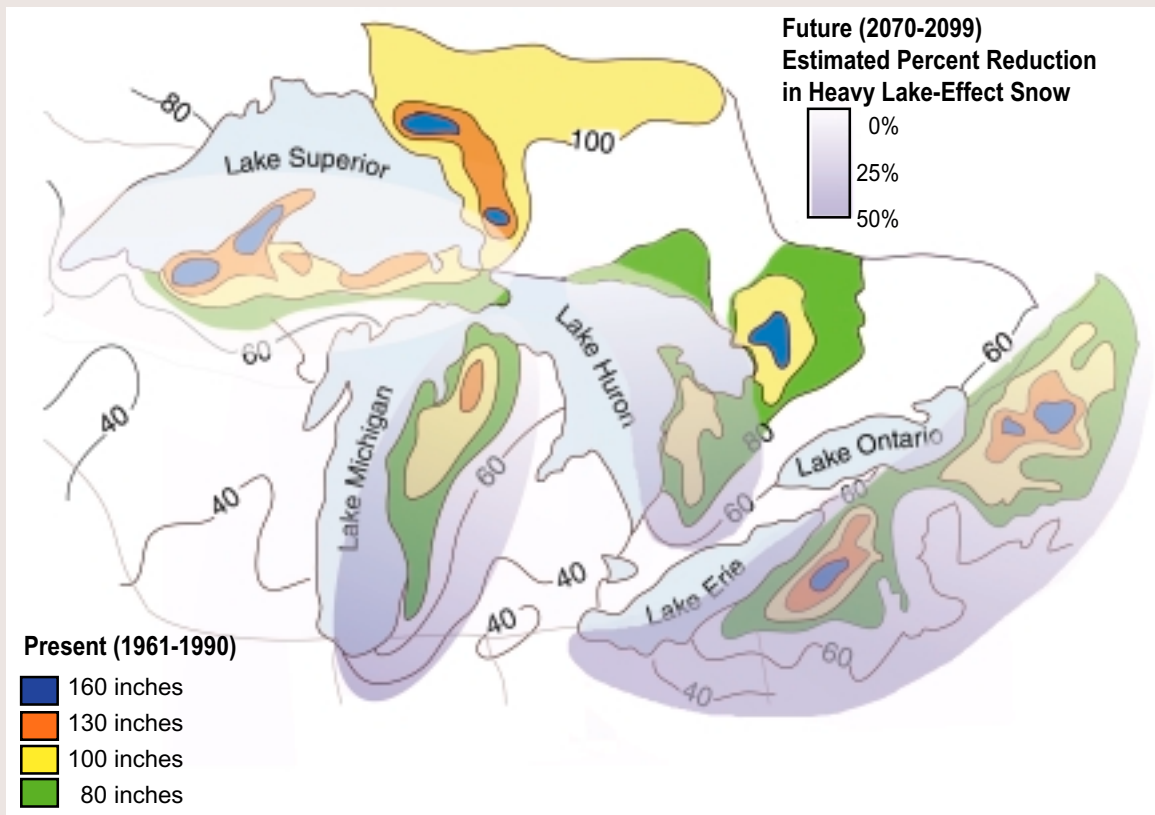

Figure F3.1: Annual snowfall totals, including both lake-effect and other types of snowstorms. Present amounts shown by contours (inches). Areas where the lake-effect causes a sizeable increase in snow amounts are highlighted in color. The impacts of climate change by 2070-2099 on heavy lake effect snow events, as estimated from HadCM2, is shown by the shading. Note that, although the shading covers the entire map, it strictly applies only to the lake-effect snow belts (colored regions) since this study did not look at all types of snow events.